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MODIFIED GAS VALVE FOR IMPROVED BALLOON DESCENT CONTROL.(U)
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-80-0333	2. GOVT ACCESSION NO. AD-A099371	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) 6 MODIFIED GAS VALVE FOR IMPROVED BALLOON DESCENT CONTROL.		5. TYPE OF REPORT & PERIOD COVERED Scientific Final rept.
		6. PERFORMING ORG. REPORT NUMBER IP No. 294
7. AUTHOR(s) 10 George F./Nolan Larry D./Wrinkle 1/Lt. USAF Bernard D./Gildenberg		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Geophysics Laboratory (LCA) Hanscom AFB Massachusetts 01731		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F 16 76591106 17 11
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory (LCA) Hanscom AFB Massachusetts 01731		12. REPORT DATE 11 30 October 1980
		13. NUMBER OF PAGES 24
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Balloon operations Helium valve Stratospheric measurements		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The ability to control balloon descent rates has been improved through use of a modified gas valve which has a range of openings. The descent rates obtained with this valve are more constant than those obtainable with the standard gas valve. Atmospheric temperature lapse rate and other thermal and aerodynamic influences are unquantifiable factors affecting balloon vertical motion but are better compensated for when use is made of a variable opening gas valve. Even with this valve, slow descents on the order of 200 fpm or		

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less will have oscillations with short periods of time when ascents and leveling off will occur.

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Preface

The work of Technical Sergeant George Clement contributed significantly to the success of this in-house work unit. Many thanks also to the members of AFGL Detachment 1 who performed the balloon operations, and to Major Kenneth Lindenfelser who provided information on gas-flow rates.

Modified Gas Valve for Improved Balloon Descent Control

1. INTRODUCTION

Helium gas valves* have been standard components on large scientific balloon systems for the past twenty years. They serve two important functions: providing a degree of control on the vertical motion of the balloon, and serving as a backup method for flight termination.** The valves are opened and closed by an electrically driven motor which is activated by radio command from either a ground station or tracking aircraft.

With a gas valve a number of useful flight profiles can be accomplished when used in conjunction with ballast drops, such as leveling off at altitudes below the balloon's natural float altitude and, to a degree, maintaining a desired ascent or descent rate. The latter procedure has become increasingly important with respect to scientific studies[1] acquiring measurements of constituents and knowledge of the chemistry of the stratosphere. Contamination problems caused by downwash

*A more detailed description of the most commonly used valve, the EV-13, is given in Section 2.

**The primary method for flight termination is the employment of rip lines which tear the balloon material upon payload separation.

(Received for publication 29 October 1980)

1. Gallagher, C. C. and Pieri, R. V. (1976) Cryogenic, Whole-Air Sampler and Program for Stratospheric Composition Studies, AFGL-TR-0161, 20 pp.

from the balloon, or outgassing from gondola components, are eliminated by taking data while descending. Whether or not atmospheric data are "clean" or contaminated has been a way for one scientist to explain differences between his data and a competitor's data. This can cause "spirited" discussion and decreased credibility in scientific findings.

Balloon descent initiated and maintained by opening and closing the helium gas valve has been difficult to control because of the nature of the valve used presently which has only two positions - fully open and closed, with a full cycle taking $\sim$ 36 sec. Slow descent on the order of 100 fpm* has become a frequent requirement in small-scale measurement and sampling investigations. Experience in trying to accomplish this with the standard valve clearly indicated that its aforementioned limitation was a major reason for marginal success in obtaining a constant slow descent. Balloons, after beginning to descend, either rise again shortly after the valve is returned to the closed position or, if the valve is left open too long, the descent soon exceeds the desired rate. In the former case the rising balloon causes contamination of the data to occur if the experiment is not shut off in time, and in the latter situation the scale of measurements or the response time for the scientific sensors can be exceeded. Much useful data have been obtained to date; however, the probability of contamination and of not meeting flight profile requirements is always present.

Looking for a way to increase the ability to control the vertical motion of a balloon it was decided to modify the standard gas valve so that a range of openings could be effected. It was thought that if the valve were kept slightly opened, thus leaking a small amount of lifting gas continuously, then slow, more constant descents could be obtained. Valves were modified, and two test flights conducted, to determine the usefulness of this concept.

2. BALLOON DYNAMICS CONSIDERATIONS

Theoretical studies have been conducted by the University of Minnesota,[2] Germeles,[3] Greenfield and Davis,[4] and Kreith[5] concerning the physics of balloon

*English units will be used throughout this report since balloon operations are like aircraft operations in regards to reporting procedures in English units for flight control by the FAA.

2. University of Minnesota Physics Dept. (1951-1954) Reports on Research and Development in the Field of High Altitude Plastic Balloons, DDC no. AD-"5998.
3. Germeles, A. E. (1966) Vertical Motion of High Altitude Balloons, Technical Report IV, A. D. Little, Inc.
4. Greenfield, S. M. and Davis, H. (1963) The Physics of Balloons and Their Feasibility as Exploration Vehicles on Mars, The Rand Corp.
5. Kreith, F. (1971) Performance of High Altitude Balloons, NCAR-TN/STR-65.

motion but the results have not been very helpful in predicting what a given balloon system will do when gas is valved, or ballast is dropped. Fairly elaborate computer programs have been written combining radiational, thermodynamic, and aerodynamic considerations in an attempt to provide predictive information on balloon behavior. Despite the good intentions, however, and the need for such investigations, the inescapable conclusion is that the best means of balloon control is to improve the control mechanisms of the balloon and the system itself, and fly it by the "seat of the pants." In addition to the gas valving and ballasting capabilities, these mechanisms include payload pointing and control systems* that reduce the effects of payload rotation and pendulousness. These systems can be quite simple, or very complicated, depending on experimental requirements. Considerable work has been done in this area that has greatly advanced the capability of balloons as scientific platforms.

The ability to control the ascent and descent of balloons to the same degree as controlling payload motion, is limited by the fact that a balloon is a body floating in a gaseous medium, the atmosphere. The complex and ever-changing heat balance of the atmosphere has a profound influence on the inflatant gas temperature and, consequently, the buoyancy of the balloon. It follows that in order to be able to predict the vertical motion of a balloon accurately, one would have to predict the heat balance of the ambient atmosphere very accurately - something which cannot be done, at least to meet real-time, operational requirements.

In this work one would like to model or predict the descent rate of the balloon, given a specified balloon system and a given valve opening. Some data are available on the flow-rate characteristics of the EV-13 gas valve, but only when it is in the full open position. The data were taken at sea level, and at the then prevailing temperature and pressure. There are no data available that give information on the effects of changing pressure and temperature similar to that which would be experienced by a balloon during flight, and there are no data for valve openings other than full open. It would have been logical to first acquire better information than now exists on the flow-rate characteristics of this valve; however, to do so adequately would be very time consuming and expensive, and it would be difficult to simulate actual flight conditions on the ground. In fact, it is doubtful if meaningful information could be obtained because of the great time and space variability of the net effect of atmospheric, solar, and terrestrial influence on balloon vertical motion.

An example of the variation in vertical motion experienced by balloons is shown in Figure 1 that depicts the departures from mean ascent rates for a number of flights. No ballast drops or gas valving occurred on these flights. The

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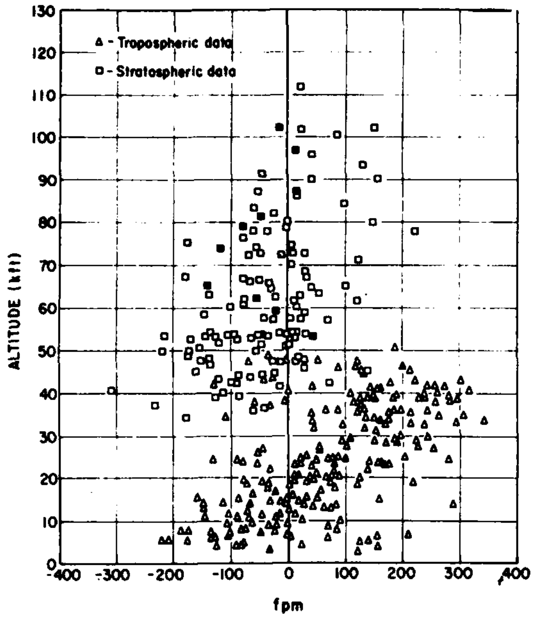
*One of these systems is described in Engineering Aspects of a Balloon Borne Astral Pointing System, Guthals, D. L. and Gibson, W. C. Proc. Seventh AFCRL Scientific Balloon Symposium AFCRL-TR-73-0071.



Departures from mean ascent rates for 37 balloon flights that were neither valved nor ballasted during ascent. Solid symbols connect departures for one of the flights. Mean tropopause height is 40,000 ft.

Figure 1. Variations in Balloon Vertical Motion

changes in ascent rate can be attributed to the interactions of aerodynamic drag and buoyancy changes caused by thermal influences. Descending balloons will be subject to similar influences, with corresponding changes in descent rates. The state of the atmospheric environment in which the balloon finds itself, therefore, has a major and little-understood influence on the vertical motion of the balloon, particularly with respect to acquiring and maintaining slow descent rates.

3. GAS VALVE MODIFICATION

The modified helium-gas valve had to be readily adaptable to existing AFGL balloon and instrumentation systems. The most cost-efficient answer was to modify the EV-13 helium-gas valve which is used routinely on all AFGL balloon flights. This valve uses an electric motor to control a 13-inch diam gas exhaust port. Telemetry consists of a voltage reply to the balloon-borne telemetry system indicating valve full-open and full-closed positions. Figure 2 shows a standard EV-13 valve in a test stand.

Figure 2. Standard EV-13 Mounted in Test Stand

Modifications to the EV-13 valves included the addition of a gear-driven potentiometer, extension of the valve dome gear rack, and recircuiting of the valve-reply signal. The PCM telemetry system was modified to provide additional valve control, and dome position telemetry. Figure 3 shows a modified EV-13 valve in a test stand.

The modified EV-13 uses a gear-driven potentiometer as a voltage divider, driven off the dome control shaft gear rack. This provides valve dome telemetry regardless of valve position; in contrast, the standard EV-13 provides telemetry only at the open and close limits. Telemetry is provided by using a 5V DC reference divided by the valve-mounted potentiometer (Figure 4), and a fixed resistor in the valve control box.

The valve control box (VCB), shown in Figures 5 and 6, interfaces the modified valve with standard AFGL balloon-control instrumentation. The VCB actually serves two purposes; first, it provides control of the valve dome position and, secondly, it houses the reference resistor used for dome position telemetry, and the RFI filter capacitors.

Figure 3. Modified EV-13 Mounted in Test Stand

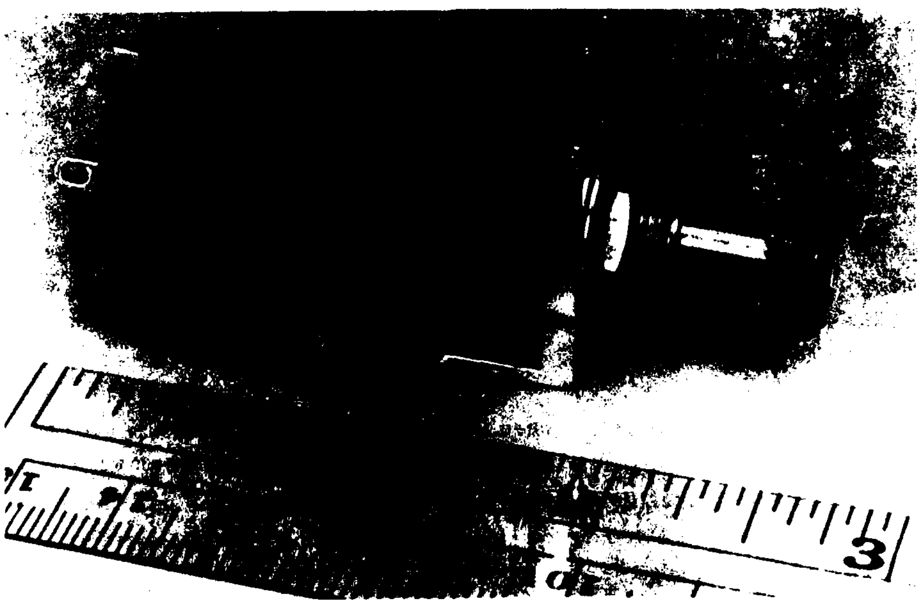


Figure 4. Gear-Driven Potentiometer and Mounting Bracket

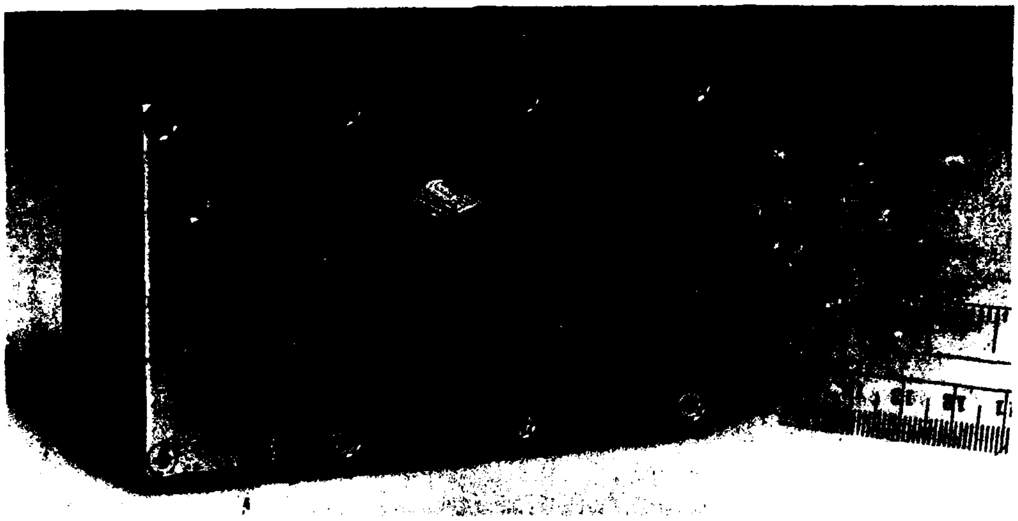
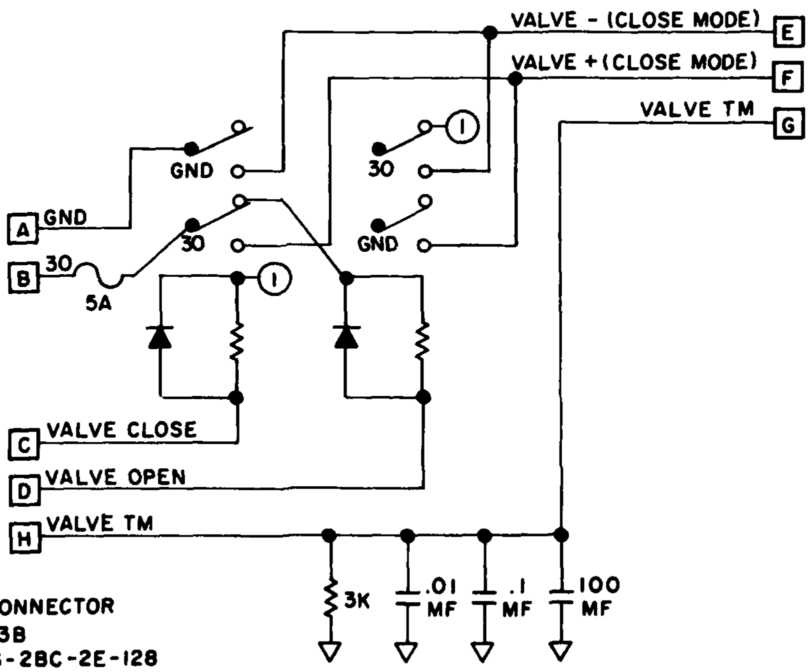


Figure 5. Valve Control Box



PTO 2A-12-10P CONNECTOR
ALL DIODES IN483B
ALL RELAYS HI-G-2BC-2E-128

Figure 6. Valve Control Box

Valve-dome telemetry (see Figure 7) is relayed to the PCM encoder through the parachute cables (see Figure 8) and the VCB interface cable (see Figure 9). The PCM data are transmitted to the ground via an S-Band carrier. At the ground station the 10-bit word containing the valve position is converted to an analog signal and displayed on a digital voltmeter. It is then an easy task, using the UHF balloon-command system, to position the valve dome as required for balloon-flight control. No modifications to the ground-station facility, other than normal patching, are required to support use of the modified gas valve.

The modified EV-13 valve was flight prepared much the same as any EV-13 valve, with the exception of a temperature test of the potentiometer. From the valve-check sheet it is easy to interpolate for various valve positions. Both the check sheet and the interpolation sheet are shown in Tables 1 and 2. Differences in the fully closed readings result from calibration of the ring-deflection setting. The standard EV-13 valve and modified valve-control components are shown in Figure 10. Valve-shaft and gear-rack assemblies for the respective valves are shown in Figure 11.

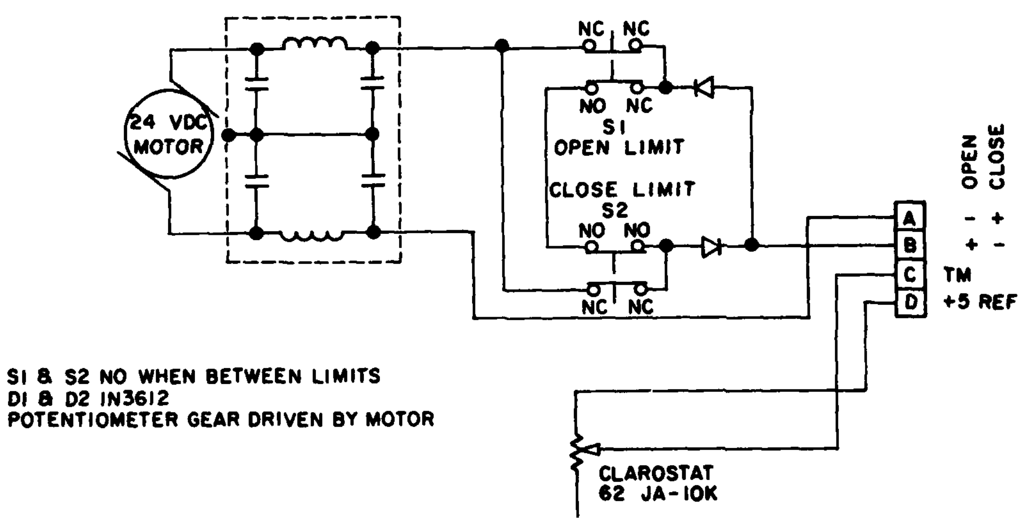


Figure 7. Modified EV-13 Valve

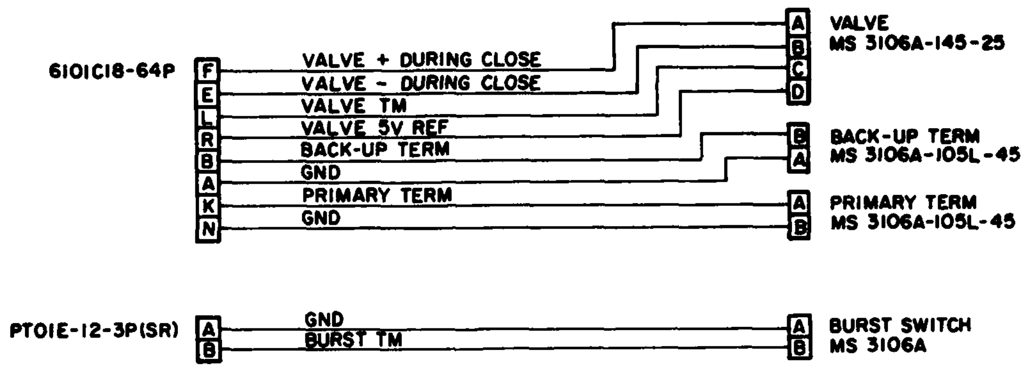


Figure 8. Parachute Cables

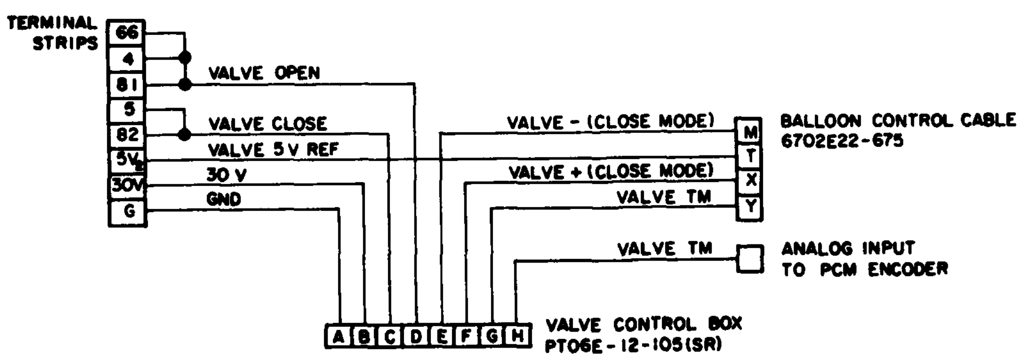


Figure 9. VCB Interface Cable

Table 1. Modified EV-13 Check Sheet

Valve #2		
5.00 V Applied	All measurements to nearest 10 mV	
Room Temperature: 23°C/73°F		
3.57 V Fully Closed	2.15 V Fully Open	
-60°C/-76°F (Minimum cold soak 1 hour)		
.35 A Motor Current		
3.57 V Fully Closed	2.16 V Fully Open	
1.41 V Difference	Difference ÷ 4 = .35 V	
Calculated		Actual
3.22 V Open 1/4	Open 1/4	3.22 V
2.87 V	Open 1/2	2.87 V
2.52 V	Open 3/4	2.52 V
2.17 V	Full Open	2.16 V

Table 2. Interpolation Sheet

Modified EV-13 #2

TM Reply

7.44 V Fully Closed
4.31 V Fully Open
7.24 V Open 1/4 inch
7.04 V Open 1/2 inch
6.85 V Open 3/4 inch
6.65 V Open 1 inch
6.46 V Open 1-1/4 inches
6.26 V Open 1-1/2 inches
6.07 V Open 1-3/4 inches
5.87 V Open 2 inches
5.67 V Open 2-1/4 inches
5.48 V Open 2-1/2 inches
5.28 V Open 2-3/4 inches
5.09 V Open 3 inches
4.89 V Open 3-1/4 inches
4.70 V Open 3-1/2 inches
4.50 V Open 3-3/4 inches
4.31 V Open 4 inches

Maximum valve opening: 4 inches
Full open cycle time: 22 seconds

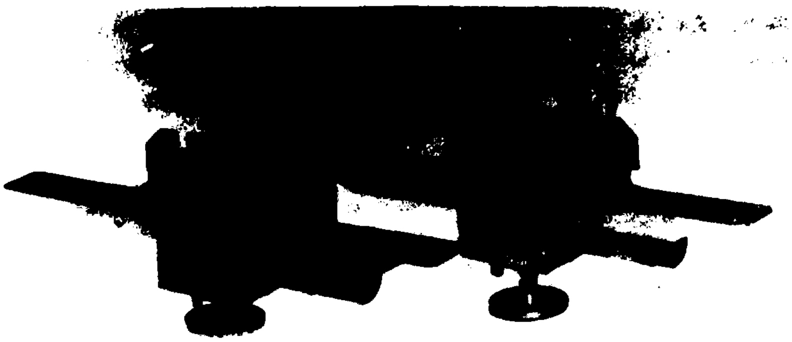


Figure 10. Valve Control Component Comparisons

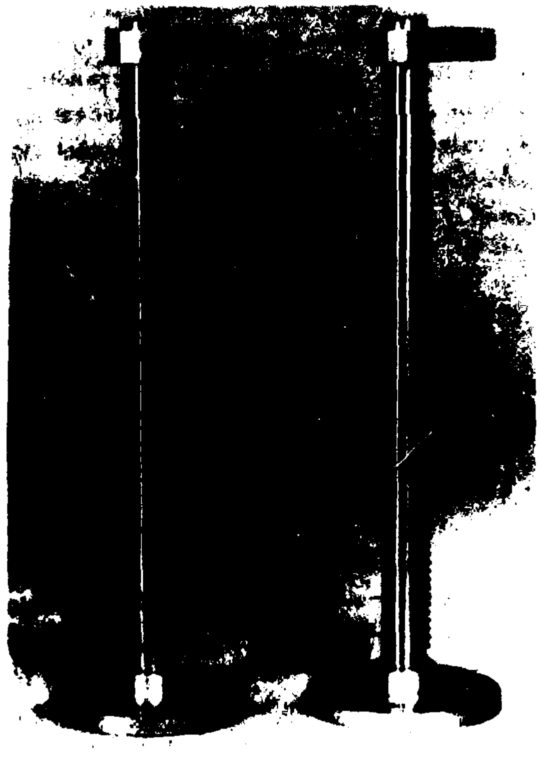


Figure 11. Shaft Comparisons

4. FLIGHT RESULTS

Two balloon flights using the modified gas valve were made from the AFGL balloon test site at Holloman AFB, New Mexico. The balloons had volumes of 516,000 cu ft and carried payloads of 1,000 lbs. This volume/payload weight gave float altitudes of ~ 78,000 ft. Each flight carried 500 lbs of releasable ballast so that a number of vertical excursions could be accomplished using different valve-opening settings. A pulse code modulated (PCM) telemetry system,[6] and a UFH command system were used to obtain data and provide flight control.

The flights also carried instrumentation for measuring shock loadings during launch and parachute deployment. These data were collected for another in-house research program and are not a part of this study.

Data were displayed on digital voltmeters and strip charts, and recorded on tape. The flights carried transponders tracked by a White Sands Missile Range (WSMR) FPS-16 radar which provided digital position and reference-time data at a rate of one readout per sec. Position accuracy is estimated by WSMR to average 30 ft RMS.

The test procedure was to ascend to float altitude, open the valve to a certain setting, and record the balloon's response. After descending approximately 5,000 ft the valve would be closed, ballast dropped, ascent again made to floating altitude and a different valve setting made, and the descent rate recorded. This procedure was followed until flight termination had to be made either for payload recovery considerations or exhaustion of ballast.

4.1 First Flight

Figures 12-15 give the significant segments of the vertical flight profile of the first flight. After reaching altitude, the balloon was allowed to float for 27 min. During this time it exhibited the typical float oscillations observed on all balloon flights having average amplitudes of about 500 ft and periods of about 4 min. Forty-seven sec of full valve was made to initiate descent. This was sufficient, and was followed, therefore, by 180 sec of full valve which caused a descent rate of 440 fpm. After the valve was closed the descent rate decreased, became positive for a short period of time, then again became negative at an average of 100 fpm. The valve was opened fully again, this time for 220 sec. A descent rate of 700 fpm was attained, which decreased to 330 fpm 5 min after the valve was closed. Ballast was then dropped, the balloon ascended at 500 fpm, a distance of about 800 ft, then began descending at 960 fpm, then 260 fpm.

6. Giannetti, A. A. and Erickson, J. C. (1980) AFGL Balloon Telemetry Facility, AFGL-TR-0029, 22 pp.

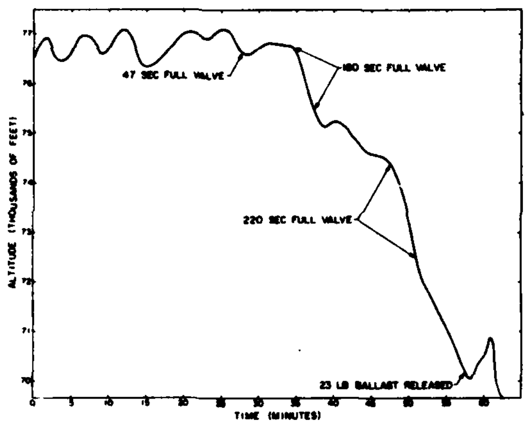


Figure 12. Time-Altitude Profiles of First Flight

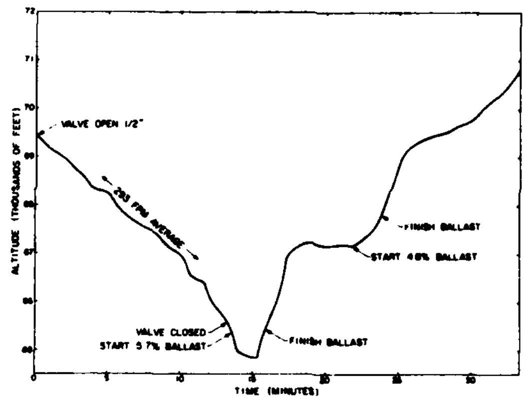


Figure 13. Time-Altitude Profiles of First Flight

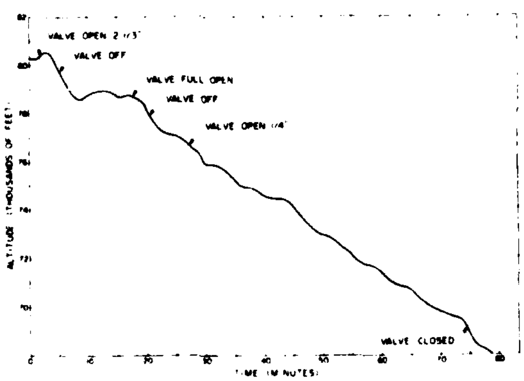


Figure 14. Time-Altitude Profiles of First Flight

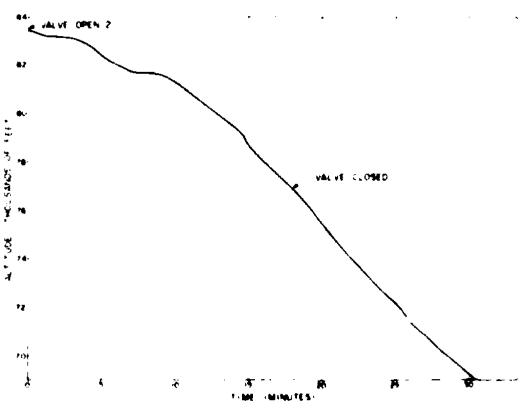


Figure 15. Time-Altitude Profiles of First Flight

The purpose of using the full open valve during this period of the flight was to illustrate the difficulty of acquiring and maintaining a steady descent rate with the conventional or standard gas valve. As mentioned in the introduction, a balloon is subjected to a very complex interplay of thermal and aerodynamic influences that make its vertical flight control difficult, and the illustration presented shows this situation.

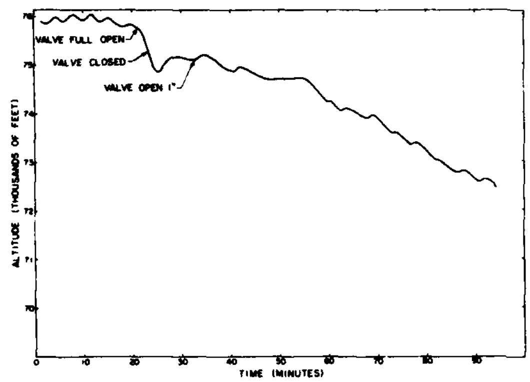
When the balloon had descended to 69, 500 ft (see Figure 13), the valve was locked open at 1/2 in. for 13 min. This resulted in an appreciably smoother descent rate than was obtained before, averaging 293 fpm. The contrast of the results of this exercise with that of the previous valving procedure indicated that use of variable open valve should significantly increase balloon-descent control.

Ballast was dropped* and the balloon ascended to a float altitude of 80, 400 ft (see Figure 14). The intention on the second descent exercise was to acquire and hold a descent rate of 200 fpm. The valve was opened this time to 2-1/3 in. Unlike during the first descent, the balloon quickly began a descent at 550 fpm. Since this exceeded the desired rate, the valve was closed, and after 5 min it leveled off. After floating for about 8 min the valve was fully opened for 160 sec. This resulted in a descent rate of 220 fpm. Subsequently, the valve was locked open at 1/4 in. for 48 min. During this period of time a very satisfactory descent rate of 202 fpm was maintained, again proving the merits of the variable open valve.

Figure 15 gives the time-altitude profile of the third descent. After reaching float altitude the valve was opened 1/2 in. for 7 min. This was not sufficient to initiate a descent. The valve was then locked open at a setting of 2 in. for a period of 25 min. This resulted in a descent rate of 212 fpm for 9 min, increasing to 482 fpm, and then 630 fpm.

This descent took place during the early afternoon when the balloon was receiving less lift due to solar heating. This could explain the gradual increase in descent rate. There is, however, the question of why a 1/4 in. opening (see Figure 14) produced approximately the same descent rate as the 2 in. opening shown in Figure 15. The answer lies in the fact that descent-rate response is altitude dependent. Here the balloon was at a mean altitude of 82, 000 ft when the valve was opened 2 in. and at a mean altitude of 73, 000 ft when it was opened to 1/4 in. This difference then is an illustration of the fact that the helium discharge rate and, consequently, the loss of buoyancy when valving, increases with decreasing altitude, other influences being the same.

*5. 7% ballast means that this percentage of the gross weight of the balloon system (1, 340 lbs) was released as ballast.



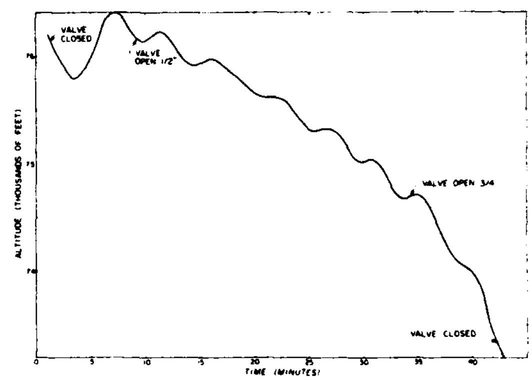


Figure 16. Time-Altitude Profiles of Second Flight

Figure 17. Time-Altitude Profiles of Second Flight

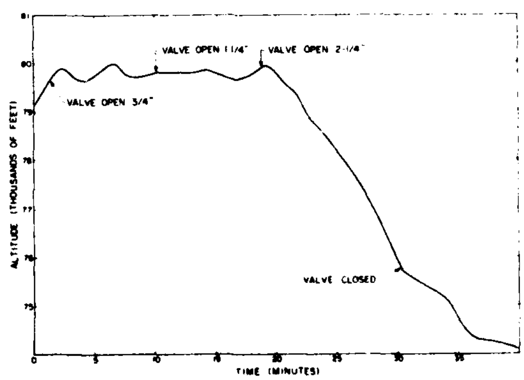


Figure 18. Time-Altitude Profiles of Second Flight

4.2 Second Flight

The balloon used on the second flight was the same in volume and weight as on the first flight. The significant portions of the resulting time-altitude profile are shown in Figures 16-18. After ascent to float altitude, the valve was opened fully for 2 min, the balloon descended 1,000 ft and, soon after the valve was closed, it rose a few hundred feet and then leveled off. The valve was then opened to a setting of 1 in. for a period of 1 hr. The balloon descended at an average rate of 47 fpm. There were a number of short period ascents and floats during this descent. At this slow descent rate the natural buoyancy oscillations that occur at float are also present here.

Figure 17 shows the results of the second descent exercise. When the balloon reached float altitude again the valve was fully opened and descent was initiated. After 8 min with the valve closed it was opened to 1/2 in. for 25 min. This caused an average descent rate of 60 fpm with oscillations similar to that exhibited on the previous descent. The valve was then opened to 3/4 in., which gave an average descent rate of 225 fpm with reduced amplitude oscillations. This increase in descent rate from 60 fpm to 225 fpm that resulted by increasing the valve opening by only 1/4 in. was unexpected; however, at the altitude at which this change in descent rate occurred, the temperature lapse rate changed to isothermal from +3.6°C per 1,000 ft. Thus, during the period of descent at 1/2 in. valve opening the ambient temperature was cooling at the latter rate and consequently the balloon was displacing, in a relative sense, denser air than would be the case in an isothermal situation. This could account for some of the difference between the two situations.

Descents from the third float were attempted with partial valve openings (see Figure 18) instead of full valve openings as was done on the previous exercises. A 3/4 in. and a 1-1/4 in. opening, each for about 9 min, failed to effect a descent. When the valve was opened to 2-1/4 in., descent began after about 1-1/2 min. An average descent rate of 381 fpm resulted at this opening.

5. CONCLUSION

Table 3 presents a summary of the average descent rates obtained during the two flights with the variable opening valve. It is immediately obvious when comparing the results that there appears to be no correlation between valve opening and descent rate. One would expect that the larger the opening the faster the descent rate. While this is disappointing, it was not entirely unexpected, given the nature and complexity of the forces acting on a balloon.

Table 3. Average Descent Rates Obtained With Different Valve Openings

	Valve Opening (inches)	Average Descent Rate (fpm)
First Flight	1/2	293
	1/4	202
	2	212
Second Flight	1	47
	1/2	60
	3/4	225
	2-1/4	381

One result, and an important one, is the evidence that the use of this modified valve will give the scientist a more constant descent rate which will aid in his data analyses and help meet his flight profile requirements. With the standard valve, the balloon operator has to perform a number of valving and ballasting adjustments to acquire and maintain a desired descent rate. With the modified valve, one can "throttle" into and hold the desired descent rate by changing valve openings.

The data show that if slow descents of approximately 200 fpm or less are desired, then the balloon will experience oscillations with periods of ascent and leveling-off occurring. These events are more pronounced at the slower rates.

As in the case of balloon ascent rates, temperature lapse rate has an important, and as yet unquantifiable, influence on descent rates. This situation, coupled with the effect of increased gas exhaustion at lower altitudes, must be considered by the balloon operator when using the modified gas valve for controlling the vertical motion of balloons.

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4. Greenfield, S. M. and Davis, H. (1963) The Physics of Balloons and Their Feasibility as Exploration Vehicles on Mars, The Rand Corp.

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6. Giannetti, A. A. and Erickson, J. C. (1980) AFGL Balloon Telemetry Facility, AFGL-TR-0029, 22 pp.